PERFORMANCE EVALUATION OF JET FUEL RESISTANT POLYMER-MODIFIED ASPHALT FOR AIRPORT PAVEMENTS

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ABSTRACT

Polymer-Modified Asphalt (PMA) is often applied at airports to improve the performance of Hot Mix Asphalt (HMA) pavements with respect to permanent deformation and cracking. Unfortunately, spillage of jet fuel softens the commonly used PMAs, resulting in a decrease of the integrity of the asphalt. Coal tar sealers, which are known to be carcinogenic, are often applied to prevent the jet fuel damage. The application of these sealers has two drawbacks; the seal coatings crack, which allows fuel to damage the HMA pavement and their use places carcinogenic material onto a pavement that may be recycled, thereby contaminating the milled RAP material. In laboratory tests jet fuel resistance has been measured by loss of material from a pavement sample after 24 hours immersion in jet fuel. Requirements of a maximum one percent weight loss after 24 hour immersion have been used to qualify an asphalt as jet fuel resistant. Standard unmodified and modified asphalts fail to meet this criteria. In 1995 Ooms Avenhorn Holding, The Netherlands, developed a coal tar free jet fuel resistant Sealoflex JR® PMA for use at the Kuala Lumpur Airport. Since that time Sealoflex JR® has been evaluated in various laboratory studies and used at airports around the world. This asphalt exhibits the excellent mechanical properties of a PMA and meets the jet fuel resistant requirement as defined by the immersion test. This material was introduced into the United States in 2002 at La Guardia Airport. This presentation will discuss these laboratory studies as well as field experiences with this asphalt.

INTRODUCTION

Polymer modified asphalt (PMA) is often applied at airports to improve the performance of asphalt with respect to resistance to permanent deformation and resistance to reflective, fatigue and thermal cracking. Best performance is usually obtained with high quality elastomer (e.g. SBS copolymer) modified asphalt. Examples of airport pavements with such PMAs are runway 9R-27L of Chicago O'Hare (the busiest runway in the world) and several runways and taxiways at Amsterdam Airport Schiphol. Unfortunately, spillage of jet fuel softens the commonly used PMAs, resulting in a decrease of the integrity (stability) of the asphalt. New York LaGuardia Airport has tested recovered asphalt samples from 15 year old pavements and found them to be softer than the AC-20 originally used because of jet fuel spills. For better skid resistance and to protect the asphalt layers from jet fuel, a jet fuel resistant friction course is often applied. These friction courses usually contain coal tar, which is known to be carcinogenic. Tar free jet fuel resistant asphalt limits the need for these harmful materials.

The first time that jet fuel resistant asphalt was specified for airport pavements was in 1995 for the new Kuala Lumpur Airport in Malaysia. The binder had to comply with the requirements for Superpave Performance Grade 76-10, while the asphalt had to meet requirements with respect to durability, resistance to deformation and resistance to cracking. A new requirement was that the asphalt had to be resistant to jet fuel, which was rated by the loss of material after 24 hours immersion in jet fuel. Standard Penetration Grade asphalt as well as common PMAs did not comply with the requirement of maximum one percent weight loss. Tar free jet fuel resistant polymer modified asphalt developed by Ooms Avenhorn Holding not only met the requirement for jet fuel resistance but also showed excellent mechanical performance. The PMA was approved by the airport consultant and applied in approximately 70% of the asphalt pavements. Production of the PMA took place in a mobile plant at the construction site.

The airport was built in 1996/1998. Since then this PMA has been used for several other airport projects, including the reconstruction of the main runway at Cairo Airport (1997), the reconstruction of Aden Airport (1999/2000), overlaying part of the apron area at Saint Maarten Airport (2001) and repair of an apron are at La Guardia Airport.

A comprehensive laboratory study has been carried out to assess the performance of the jet fuel resistant PMA and the asphalt in which this PMA is applied. The rheological behavior of both fresh asphalt and asphalt recovered from asphalt specimens is determined. Some of the asphalt specimens were first kept in jet fuel for a certain time before the asphalt was recovered. Asphalt specimens, both treated (24 hours in jet fuel) and untreated, were tested for their resistance to permanent deformation and their fracture characteristics at low temperature. The results are compared with the rheological behaviour of standard Penetration Grade asphalt and high quality SBS modified asphalt and the performance of asphalt in which these binders are applied.

This paper presents the results of the laboratory study into the performance of jet fuel resistant polymer-modified asphalt and asphalt mixes containing fuel resistant asphalt. Also discussed are the field experiences with this binder at the airports of Kuala Lumpur, Cairo, Aden, Saint Maarten (Netherlands Antilles) and La Guardia.

LABORATORY PERFORMANCE EVALUATION OF JET FUEL RESISTANT PMA

Laboratory studies were carried out to characterize the jet fuel resistant PMA (PMA JR[1]) and compare its performance with that of standard Penetration Grade asphalt (Pen 40/60) and a PMA (PMA S[2]) with proven good performance at Amsterdam Airport Schiphol. The studies included both asphalt properties and asphalt mixture properties.

To obtain insight in the viscoelastic behaviour of each asphalt, repeated creep-recovery tests at 40°C were carried out and mastercurves for complex shear modulus (G*) and phase angle (δ) were determined. To allow for changes in properties that occur during production and construction, testing was done on asphalt that was recovered from a laboratory made asphalt mixture (porous asphalt with 4.5 % asphalt and 20 % air voids). To study the effect of jet fuel on the properties and behaviour of each asphalt, testing was also done on asphalt that was recovered from the laboratory made asphalt mixture after it was kept immersed in jet fuel for three hours and then dried for 5 days in flowing air. The tests were carried out with a Dynamic Shear Rheometer (Paar Physica UDS200). Since asphalt specifications are still often based on Penetration at 25°C and Softening Point Ring&Ball of fresh asphalt, these properties were also determined.

The repeated creep-recovery tests included 17 creep-recovery cycles. During each cycle a load of 10 kPa was applied for a period of 11 s, followed by a recovery period of the same duration. During the tests the deformation was continuously recorded. Time-deformation curves are shown in Figures 1 and 2. The difference in viscoelastic behaviour of the two PMAs and the

[1] Sealoflex® SFB 5-JR-50
[2] Sealoflex® SFB 5-50

Pen 40/60 asphalt is clearly illustrated in figure 1. At the end of the test the permanent deformation of the two PMAs is about ten times less than for the Pen 40/60 asphalt. This is due to less deformation during the loading periods (i.e. the PMAs are stiffer than the Pen 40/60 asphalt) and more recovery during the unloading periods (i.e. the PMAs are more elastic than the Pen 40/60 asphalt).

The difference is even greater when the asphalt is recovered from asphalt specimens that were first immersed in jet fuel; the permanent deformation of the two PMAs remains at the same level (Figure 2), while the deformation of the Pen 40/60 asphalt is about 15 to 20 times higher. Figure 2 also indicates that jet fuel has some effect on the stiffness of PMA S (stiffness is lower) but does not influence the elasticity. The behaviour of the PMA JR seems to be even improved.

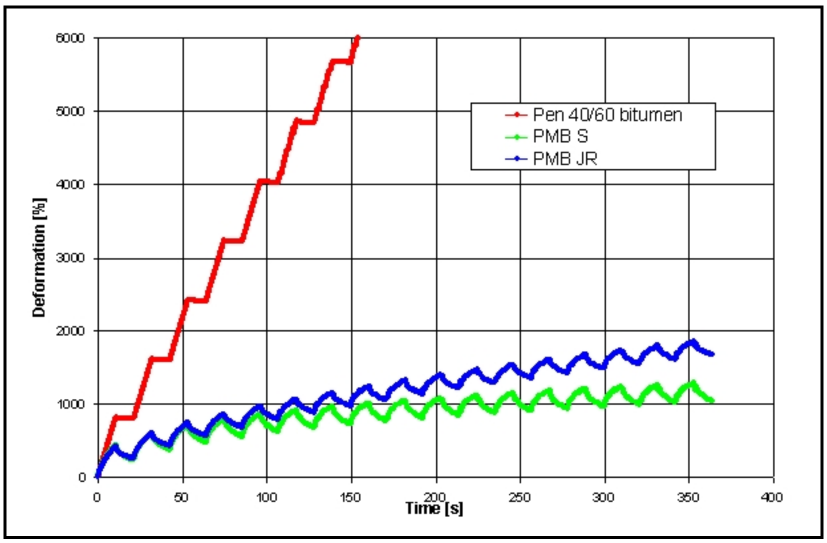

Figure 1. Results of repeated creep-recovery tests at 40°C (not conditioned).

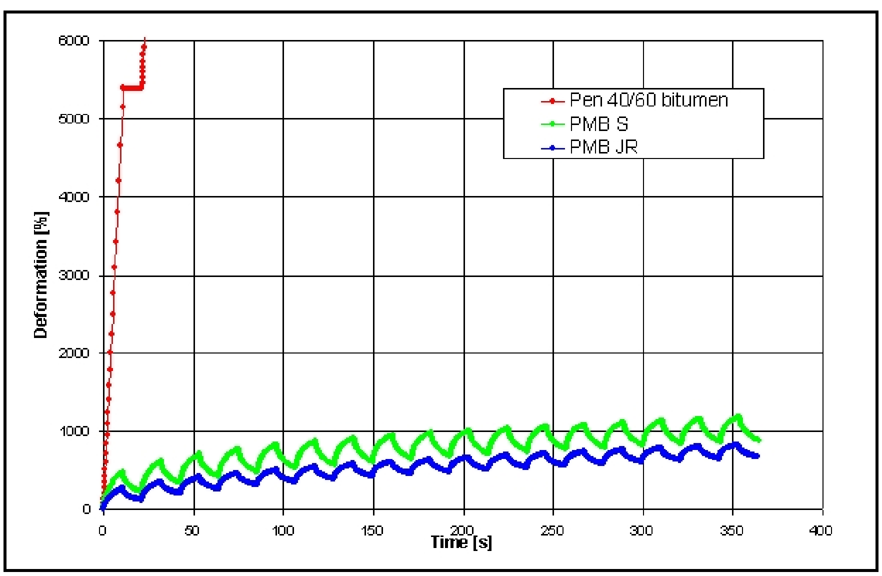

Figure 2. Results of repeated creep-recovery tests at 40°C (after immersion in jet fuel).

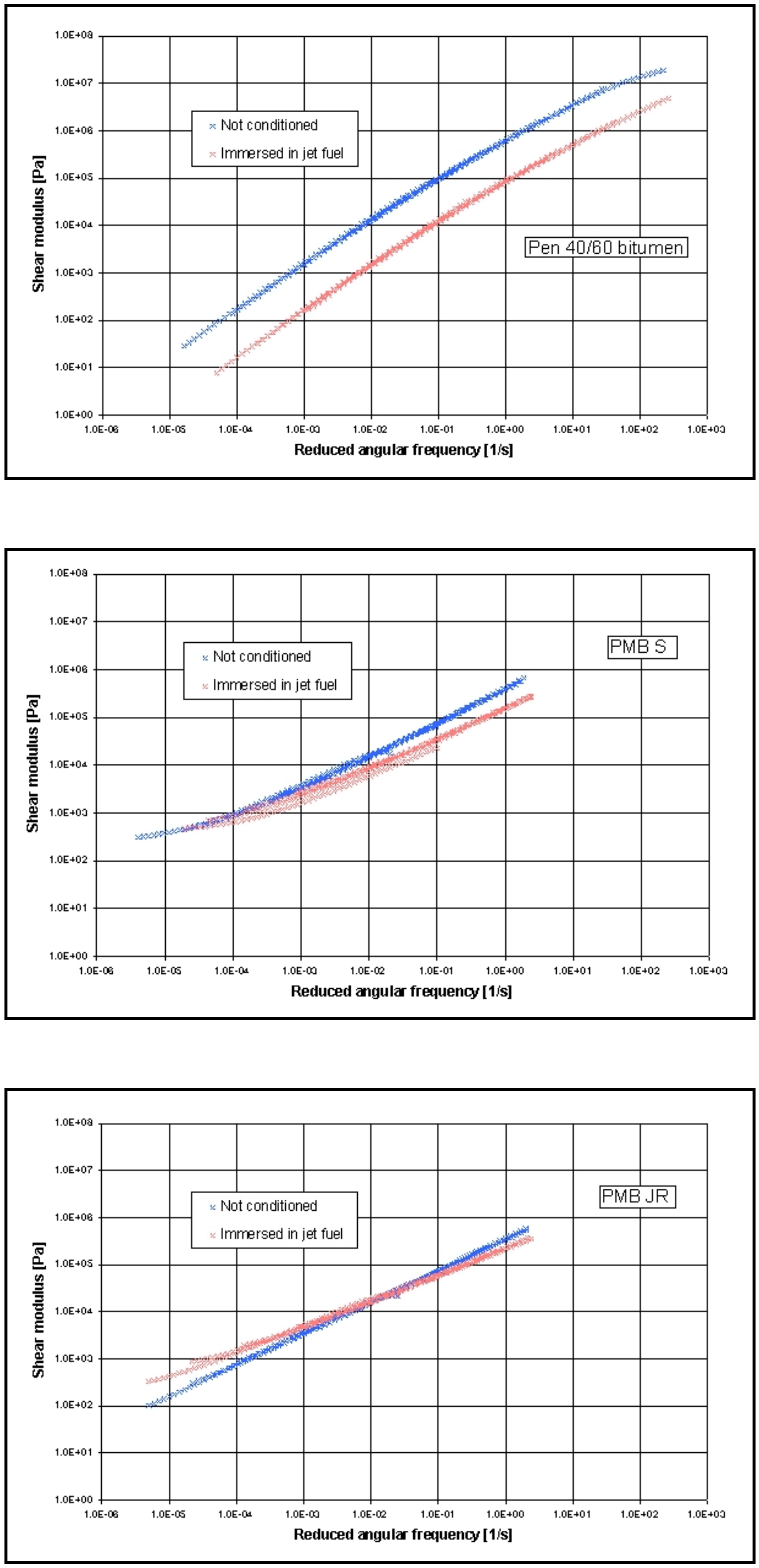

Figure 3. Mastercurves for complex shear modulus of Pen 40/60 asphalt (top), PMA S (middle) and PMA JR (bottom) (T_{ref}: 20°C).

The effect of jet fuel on the complex shear modulus (G*) is shown separately for each asphalt in Figure 3. The complex shear modulus of Pen 40/60 asphalt is reduced by a factor of ten for all frequencies. The behaviour of PMA JR seems to be improved: higher complex shear modulus at low frequencies (long loading times) and lower complex shear modulus at high frequencies (short loading times). The effect on PMA S was a reduction of the complex shear modulus at high frequencies. From the mastercurves for the phase angle (not shown in the paper) it can be concluded that Pen 40/60 asphalt becomes more viscous at all frequencies and the two PMAs become more elastic at lower frequencies.

The values for Penetration and Softening Point of the asphalt are shown in Table 1. Based on these properties it can be concluded that all three asphalt are to some extent softened by jet fuel. The effect is largest for Pen 40/60 asphalt (300 % increase in Penetration) and smallest for PMA JR (20 % increase in Penetration).

Table 1.
Standard Asphalt Properties.

	Penetration at 25°C [0.1 mm]	Softening Point R&B [°C]
Pen 40/60 asphalt:		
Fresh	55	50.5
Recovered (no conditioning)	50	51.6
Recovered (immersed in jet fuel)	148	40.1
PMA S:		
Fresh	61	101.5
Recovered (no conditioning)	50	97.5
Recovered (immersed in jet fuel)	79	92.0
PMA JR:		
Fresh	56	86.0
Recovered (no conditioning)	54	82.0
Recovered (immersed in jet fuel)	65	79.0

With regard to the asphalt mixture properties, Marshall specimens of dense-graded hot mix asphalt (HMA) were made with each asphalt and subsequently tested for their fracture characteristics at a low temperature (tensile strength and fracture energy) and their resistance to permanent deformation at a high temperature. Both untreated specimens and specimens that were kept immersed in jet fuel for 24 hours were tested.

It has been shown that the resistance to reflective cracking is related to the tensile strength and fracture energy of an asphalt mixture [4]. Generally, to prevent or delay reflective cracking, asphalt mixtures with high tensile strength and high fracture energy are preferred. These properties can be determined by means of a monotonic indirect tensile strength test (splitting test). For this study the tests are carried out at a temperature of 0°C and a deformation rate of 0.85 mm/s. The results are shown in Table 2. The asphalt mixtures with PMA show higher tensile strength and fracture energy than the asphalt mixture with Pen 40/60 asphalt. The tensile strength after immersion in jet fuel is for all three asphalt mixtures lower. However, for the mixtures with PMA the fracture energy has become higher.

The resistance to permanent deformation is often assessed by means of a uniaxial cyclic compression test. Parameters to quantify the resistance to permanent deformation are the permanent deformation at the end of the test and the mixture viscosity. The latter is calculated from the linear part of the time-deformation curve and is a measure for the resistance to permanent deformation of a viscous nature. To limit viscous deformation a high mixture viscosity is preferred. For this study the tests were carried out at a temperature of 40°C. Each specimen was subjected to cyclic vertical loading without confining pressure. The load was applied during 0.3 s. The duration of one complete load cycle (load plus rest period) was 1.0 s. The magnitude of the load was 0.4 MPa. The test was stopped at 7 % permanent deformation or 10,000 load cycles, whatever came first. During the test the permanent deformation was recorded continuously. The results of the tests are shown in Table 2. The time-deformation curves for the Marshall specimens that were kept in jet fuel are shown in Figure 4. The results show that use of PMA S or PMA JR significantly improves the resistance to permanent deformation and also that the performance of PMA JR is not affected by jet fuel. This confirms the results of the repeated creep-recovery tests that were carried out on the asphalt itself.

Table 2.
Asphalt mixture properties.

	Fracture characteristics at 0°C		Resistance to deformation at 40°C	
	Indirect tensile strength [MPa]	Fracture energy [Nmm/mm^2]	Permanent deformation [%]	Mixture viscosity [GPa·s]
40/60 asphalt:				
Not conditioned	4.6	8.3	4.9	52
Immersed in jet fuel	4.1	7.1	> 7.0	31
PMA S:				
Not conditioned	5.2	11.4	1.7	940
Immersed in jet fuel	3.6	21.5	2.5	410
PMA JR:				
Not conditioned	5.4	13.8	1.3	1,050
Immersed in jet fuel	4.4	16.0	1.4	1,050

The resistance to jet fuel (or any other fluid) can be assessed by keeping asphalt specimens immersed in jet fuel for a certain period of time (e.g. 24 hours) and measuring the loss of weight. The loss of weight typically ranges from less than 0.5 % for asphalt mixtures with jet fuel resistant asphalt to more than 10 % for asphalt mixtures with standard asphalt. A shortcoming of this method is that changes inside the asphalt mixture (e.g. reduction of adhesion quality between aggregate and asphalt), which do not result in a direct loss of material, are not assessed. Therefore, a method was developed by Buijs and Van Buël [2], which incorporates both chemical and mechanical loading. The main differences with the immersion method previously mentioned are that only one side of the specimen is kept immersed in the fluid and that the loss of weight is measured after the chemically treated side has been mechanically “brushed” during two minutes with a steel brush. In Table 3 some loss of weight values are shown for asphalt mixtures with different asphalt, which are determined according to this so called “brush test.”

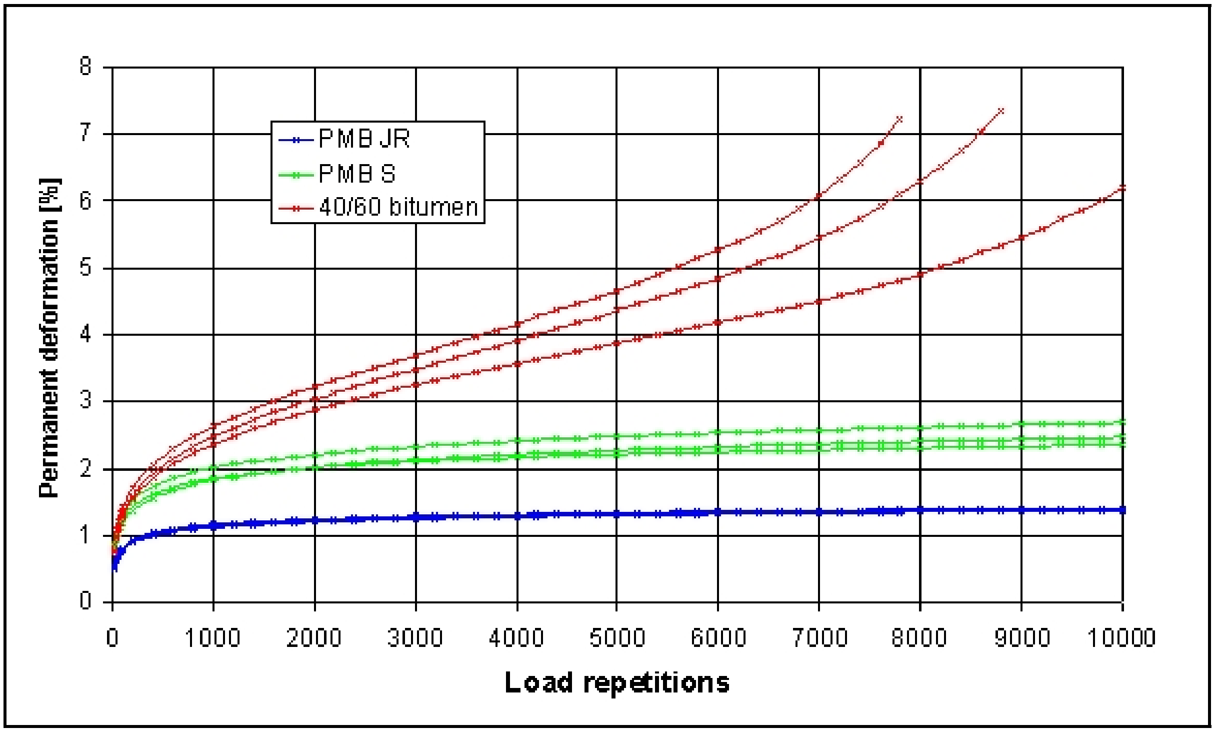

Figure 4. Time-deformation curves of uniaxial cyclic compression tests at 40°C (after immersion in jet fuel).

Table 3.
Resistance to Jet Fuel According to the "Brush Test" [2].

	Loss of weight of asphalt specimen [%]	
	24 hours immersed	72 hours immersed
Pen 70/100 asphalt	9.2	13.9
PMA A	4.0	6.8
PMA B	4.1	9.6
PMA C	3.5	7.5
PMA D[1]	3.8	6.6

FIRST FULL-SCALE APPLICATION OF JET FUEL RESISTANT PMA AT KUALA LUMPUR INTERNATIONAL AIRPORT

The first large airport project where PMA JR was applied was the new Kuala Lumpur International Airport (KLIA) in Malaysia in 1996. This was the first airport that specified jet fuel resistant asphalt pavements. In addition to requirements for the jet fuel resistance of the PMA itself, as determined according to ASTM D3320, paragraph 6.12 [1], there was also a

[1] Sealoflex® SFB 5-JR-50

requirement for the jet fuel resistance of the asphalt mixture. The asphalt mixture was considered to be jet fuel resistant when the average loss of weight of four Marshall specimens, that were kept immersed in jet fuel for 24 hours, was less than 1%. Besides, the PMA had to comply with the requirements for a Superpave Performance Grade 76-10 and the polymer modified asphalt (PMA) had to comply with requirements related to resistance to permanent deformation and resistance to reflective cracking. The most important PMA and HMA requirements are given in Table 4.

Table 4.
PMA and PMA requirements Kuala Lumpur International Airport [6].

PMA requirements:	
Flash point	Min 230°C
Softening point	Min 60°C
Superpave Performance Grade	Min PG 76-10
HMA requirements:	
Indirect tensile strength at 25°C	Min 1.0 MPa
Fracture energy at 25°C	Min 8.0 Nmm/mm^2
Total resilient modulus at 25°C	Min 2,500 MPa
Creep Modulus at 40°C, 60 min, 300 kPa	Min 75 MPa
Creep slope at steady state	Max 0.25

The new asphalt pavements typically consist of 450 mm cement-treated base, a crack relief layer of 100 mm thick HMA with conventional asphalt and 150 mm of HMA containing PMA [6]. PMA JR was applied in approximately 70% of the asphalt pavements. Production of the PMA took place in a mobile plant at the construction site. Construction work started in 1996 and was completed in 1998. Approximately 260,000 tons of HMA containing PMA JR were placed. Airport management reports the pavement is in excellent condition today (illustrated in Figure 5), showing no signs of rutting or cracking.

Figure 5. Kuala Lumpur Airport

AIRPORT APPLICATIONS IN THE MIDDLE EAST

The same PMA was used for two airport projects in the Middle East: rehabilitation and upgrading of the runway and taxiways at Cairo International Airport in 1997 and rehabilitation of the runway at Aden International Airport in 1999. The PMA and HMA requirements were comparable to those of the new Kuala Lumpur Airport.

Cairo International Airport is the busiest airport in the Middle East. The main distress at the surface of the existing asphalt pavements was cracking and ravelling [5]. The asphalt of the wearing course (originally Pen 60/70) appeared to be severely aged (Penetration at 25°C of 10 to 20 and a Softening Point R&B of 70 to 80°C). For the new wearing course jet fuel resistant PMA was required. This asphalt had to comply with the requirements for Superpave Performance Grade 76-10. The asphalt that was selected for modification was a local standard Pen 60/70 asphalt with Superpave Performance Grade 64-16. The Performance Grade after modification was 76-22. This means that the high temperature performance (i.e. resistance to permanent deformation) was improved by two grades and the low temperature performance (i.e. resistance to cracking) was improved by one grade.

The existing pavement was largely kept intact. It consisted of 350 mm Portland cement concrete with about 250 mm asphalt placed as several overlays since 1980. Rehabilitation typically consisted of a crack relief layer (60 mm) and two dense asphalt layers with PMA (60 mm each) [6]. Construction work started at the end of 1997 and was finished eight months later. During this period approximately 220,000 tons of jet fuel resistant asphalt was applied. The production of the PMA took place in a mobile plant at the construction site. From the production control data it became apparent that the PMA from the first batches was more viscous at higher and intermediate temperatures than the PMA that was prepared (designed) in the laboratory. This was probably caused by differences between the base asphalt used in the design study and the base asphalt that was supplied on the site. Some small adjustments to the production procedure resulted in a softer (less viscous) PMA. Some properties of the PMA prepared in the laboratory, the PMA from the first batches and the PMA from later production are given in Table 5.

For Aden International Airport the PMA had to meet the requirements for Superpave Performance Grade 70-10. Modification of a local Pen 70/100 asphalt resulted in a PMA with a Performance Grade of 82-16, which is three grades better than specified. Construction work was carried out in 1999/2000. During this period approximately 40,000 tons of jet fuel resistant asphalt was placed.

Fuel resistant pavements at both Cairo and Aden Airports are performing well to date. There is no evidence of fuel related damage, rutting or cracking at this time.

Table 5.
PMA properties Cairo International Airport.

	Lab	Oct 97	Dec 97	Jan 98	Mar 98	Requirements
Fresh asphalt:						
Penetration at 25°C	45	39	46	54	54	-
Softening Point	90.5	94.0	91.0	66.0	72.5	Min 60.0°C
Shear viscosity at 135°C	2.7	6.5	2.2	2.0	1.8	Max 3.0 Pa·s
$G^*/\sin\delta$ at 76°C	2.5	4.5	2.2	1.4	1.3	Min 1.0 kPa
RTFOT aged asphalt:						
$G^*/\sin\delta$ at 76°C	2.9	11.0	4.0	2.4	2.7	Min 2.2 kPa
PAV aged asphalt:						
$G^*\cdot\sin\delta$ at 37°C	-	441	775	680	637	Max 5,000 kPa
BBR stiffness S at 0°C	-	48	55	64	63	Max 300 MPa
BBR slope m at 0°C	-	0.316	0.347	0.434	0.417	Min 0.300

JET FUEL RESISTANT PMA AT THE INTERNATIONAL AIRPORT OF SAINT MAARTEN (NETHERLANDS ANTILLES)

At the International Airport of Saint Maarten the asphalt pavements were usually made with Trinidad Lake Asphalt (TLA). Results of a laboratory study clearly showed the improvement in resistance to permanent deformation at high temperatures when PMA S was used instead of TLA. Because resistance to jet fuel was also required, it was decided to use PMA JR for the asphalt overlay at part of the apron area. For this purpose, PMA JR concentrate was shipped from the Netherlands in special self-heated tank containers to Saint Maarten. Using the PMA JR concentrate and locally available Pen 60/70 asphalt, PMA JR was produced by means of let down processing and chemically curing. Construction work was carried out in 2001. In total about 600 tons PMA JR was utilized. The pavement is in excellent condition at the time of this paper.

The resistance to permanent deformation was again assessed by means of a uniaxial cyclic compression test. Because at Saint Maarten the pavement temperatures can become very high, the tests were carried out at a temperature of 60□C. Each specimen was subjected to cyclic vertical loading without confining pressure. The load was applied during 0.2 s. The duration of one complete load cycle (load plus rest period) was 2.0 s. The magnitude of the load was 0.4 MPa. The test was stopped at 12 % permanent deformation or 10,000 load cycles, whatever came first. The first series of tests were performed on four Marshall specimens with PMA S and TLA. Later also two Marshall specimens with PMA JR from Saint Maarten (PMA JR produced as described above) were tested. The time-deformation curves of all six specimens are shown in Figure 6.

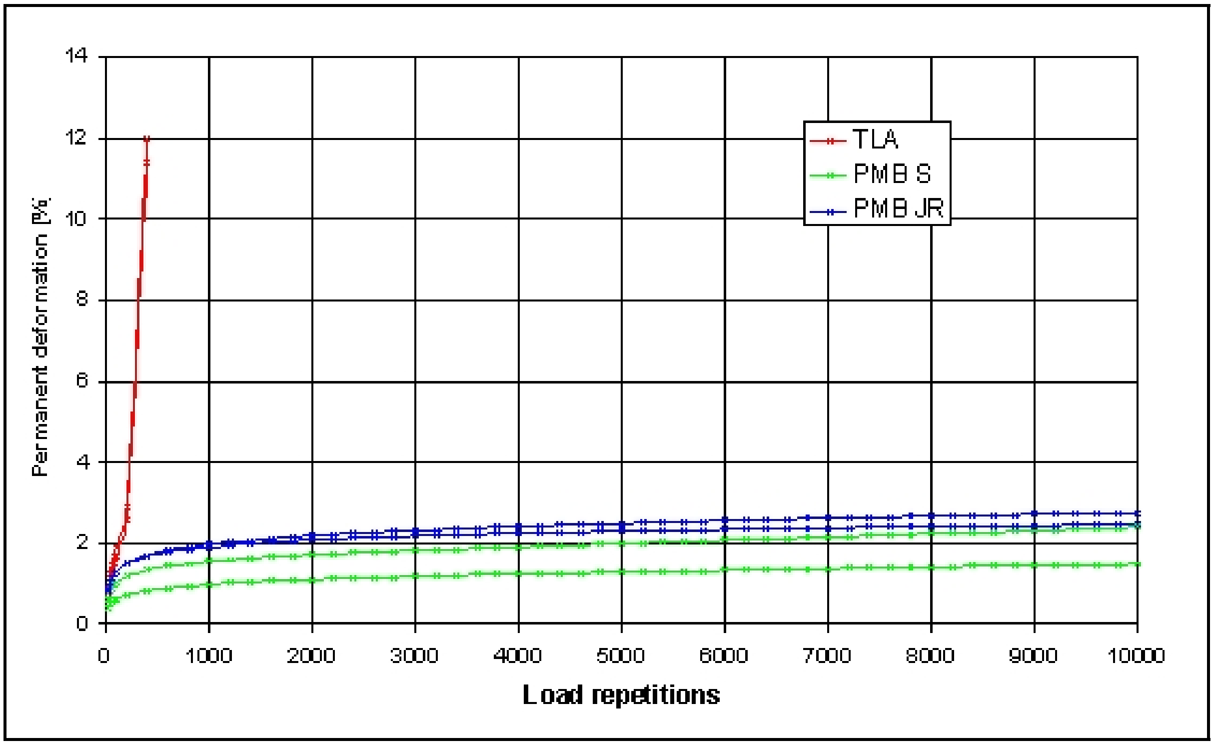

Figure 6. Time-deformation curves of uniaxial cyclic compression tests at 60°C for Saint Maarten.

FUEL RESISTANT PMA AT LA GUARDIA AIRPORT

La Guardia Airport, located in Queens, NY, routinely experiences heavy aircraft traffic loadings and standing traffic on its aprons and taxiways. Jet fuel and hydraulic oil spills have softened the pavements and contributed to unacceptable rutting. The Port Authority of New York and New Jersey, the owner agency for the airport, currently specifies PMA with a Performance Grade of PG 82-22 to provide resistance to permanent deformation and cracking on the HMA pavements.

CITGO Asphalt Refining Company produced samples of the Ooms Avenhorn fuel-resistant PMA in its laboratory in 2001. Tests were performed on both the PMA and a P401 mixture containing the PMA to confirm performance after submersion in jet fuel. A report of this testing was presented to The Port Authority of New York and New Jersey in 2001 and they requested samples of the asphalt for testing in their laboratory. The PMA would have to meet or exceed the PG 82-22 currently specified. The material supplied for this project met a Performance Grade of PG 94-22. Following laboratory testing in the winter of 2001, The Port Authority requested that CITGO Asphalt provide one tanker load (25 tons) of CITGOFLEX FR PG 94-22 for a test strip at La Guardia.

The project at La Guardia required milling and replacing 14” of existing pavement on a distressed taxiway. The bottom 11” would contain PG 82-22 and the 3” surface would contain the fuel resistant PG 94-22. The work was performed in August 2002.

The PMA was pumped directly from the tanker into the plant, because of the lack of available storage tanks. The temperature at the time of unloading was 330°F, and the HMA batch plant was able to pump and mix the asphalt without problem. The contractor produced approximately 400 tons of mix containing PG 94-22 at a temperature of 340°F and placed it in storage silos at approximately 2:00 PM. The logistics of the project, including time for cooling of each HMA layer, delayed the paving of the fuel resistant mix until 8:00 PM. Placement and compaction of this mix took place at 330°F without problems. Handwork and the longitudinal joint construction were accomplished without difficulty. The paving crew testified that they could see no difference between the fuel resistant PG 94-22 and the PG 82-22. The mat texture and appearance were similar to the mix containing PG 82-22 asphalt.

A visual inspection of the project at La Guardia was conducted in October 2003. No measurable rutting was evident under a 10" straightedge. There was no evidence of cracking, ravelling or fuel-induced damage in the pavement.

CONCLUSIONS

Coal-tar free jet fuel resistant polymer modified asphalt was developed by Ooms Avenhorn Holding and successfully applied at a number of International Airports.

Results from laboratory tests have shown the dramatic collapse of integrity of standard asphalt and asphalt after immersion in jet fuel, while the mechanical properties of specially developed jet fuel resistant asphalt and asphalt were not or hardly affected.

Pavements have been constructed using jet fuel resistant asphalt at five airports around the world beginning in 1996, and performance has been excellent to date.

REFERENCES

1. ASTM, *Annual Book of ASTM Standards, Part 15: Road, Paving, Bituminous Materials, Travelled Surface Characteristics*, 1982.
2. Buijs, J., and Van Buël, T., *Chemical resistance of asphalt* (in Dutch), Hogeschool `s-Hertogenbosch, 2001.
3. De Bondt, Dr. Ir. A.H., and Van Rooijen, Ir. R.C., *Asphalt specified for airports* (in Dutch); CROW Workshop vliegveldverhardingen, 1997.
4. Jacobs, Dr. Ir. M.M.J., *Crack growth in asphaltic mixtures*; Ph.D. thesis; 1995.
5. Khan, Dr. Shahid S., "Sealoflex for Airport Pavement Construction and Rehabilitation," Sealoflex World Conference, Tokyo, 1999.
6. Nataraj, Ir. A.R., "Use of Polymer Modified Asphalt Mixes in Airport Pavements – Design Approach and Case Histories," International Sealoflex Conference, Rome, 2001.